Attachment #3

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Title: Conservation and Management Implications of Deep-Sea Coral and Fishing Effort Distributions in the Northeast Pacific Ocean

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Abstract

The conservation of deep-sea corals is of growing interest in the United States. A range of issues including biodiversity protection, conservation of seafloor habitats, and the role of deep-sea corals as essential fish habitat (EFH) places greater significance on understanding the distributions of these corals and fishing activities. At the same time, overfishing of some groundfish populations highlights the need for ecosystem-based management. Here we present records of habitat-forming deep-sea corals from the United States Pacific Fishery Management Council region that we analyze in relation to differential ecological impacts of demersal fishing gears. We use an ecological footprint approach combining groundfish catch by gear type with a previously published ecological severity ranking of fishing gears.

Deep-sea corals in the Isididae, Paragorgiidae, Primnoidae, Antipathidae and Stylasteriidae families are widespread throughout their depth ranges in the Northeast Pacific, although the scleractinian families Oculinidae and Caryophylliidae are relatively rare. In this qualitative analysis, we highlight areas of relatively high coral concentration such as the West Coast continental shelf break and Monterey submarine canyon, areas that are presently relatively lightly fished but where corals are recorded. Bottom trawling gear has far and away the region's largest ecological footprint. Other gears with smaller footprints include bottom longline, pot/trap and hook and line gear. Most of these impacts seem to have occurred in areas where deep-sea corals are relatively scarce, but fishing closures to protect rockfish implemented in 2002 may have the unfortunate effect of redistributing fishing effort to areas of deep-sea coral aggregations. An ecosystem-based management approach would detect and prevent such unintended consequences of redistributing fishing effort and placing deep-sea corals in harm's way.

Introduction

Deep-sea corals are a paraphyletic assemblage of organisms belonging to the phylum Cnidaria. Some corals are more closely related to sea anemones than other "corals" such as hyrdocorals. Moreover, some species usually considered deep-sea corals can be found in shallow waters (<200m). Following Etnoyer and Morgan (2003) we use the term deep-sea coral to refer to a variety of hexacoral, octocoral, and hydrocoral families living in temperate waters.

In general, deep-sea corals are a poorly documented group that are increasingly at the center of conservation concern because they are considered important habitat for commercially important fishes, as well as a wide variety of other fishes and invertebrates. On the Atlantic Coast of the US deep-sea corals occur from Georges Bank (e.g., *Paragorgia arborea*), to *Lophelia* reefs such as the Agassiz coral hills on the Blake Plateau in the mid-latitudes of North Carolina (George 2002) to the *Oculina* (*Oculina varicosa*) Banks of Florida (Reed 2002). Deep-sea coral records in the Northeast Pacific date to the late 19th century (Dall 1884). Contemporary concerns such as biodiversity conservation, commercial fishery sustainability, benthic impacts of commercial fishing gears and EFH are revitalizing interest in the distribution and abundance of habitat-forming deep-sea corals (e.g., Witherell and Coon 2001; Etnoyer and Morgan 2003).

In 1996, the US Congress revised the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), changing the way fisheries are managed. Key additions include reducing bycatch, avoiding overfishing and identifying Essential Fish Habitat (EFH). These measures also provide an option for decision-makers to designate habitat areas of particular concern (HAPC), as in the case of protecting *Oculina* Banks off Florida--a spawning area for commercially important snappers and groupers--from trawling and other forms of fishing (Reed 2002). Proposals to protect corals with similar HAPC designations are being developed in other areas of the US Exclusive Economic Zone (EEZ). Interest in Pacific deep-sea corals is driven by declining catches of groundfish (Ralston 1998; Pacific Marine Conservation Council (PMCC) 1999; Fig. 1), which may need coral habitat in various life stages.

In January 2000, the US Secretary of Commerce declared the West Coast groundfish fisheries a federal disaster. Groundfish is a general term used for 83 species of demersal fishes that are managed by the Pacific Fishery Management Council (PFMC), whose jurisdiction includes the federal and state waters off California, Oregon and Washington. These species are targeted by fishermen using trawl nets, bottom longlines, pots/traps, and hook and line gears. A substantial number of managed groundfish are rockfishes in the genus *Sebastes*. Approximately 55 species of rockfishes are targeted by fishermen and marketed under the generic term 'red snapper' (PMCC 1999). Currently nine of the 83 managed west coast groundfish species are listed as "overfished" by NOAA Fisheries, the federal agency responsible for managing fisheries in US federal waters.

Recent management action to protect declining groundfish has closed areas along a restricted depth interval of the continental shelf from Mexico to Canada beginning in the 2002 season. Under the provisions of MSFCMA, fisheries managers are required to adopt the precautionary approach when scientific data are unavailable. In essence this means that wherever fishing poses a threat to the resource and/or the surrounding environment, precautionary measures must be taken even if the scientific results are not yet established. However, in practice the case for protection of corals from destructive fishing methods and their role as important seafloor habitat has typically been left as a "case to be made," and little precautionary action has been taken to protect them from fishing threats.

Habitat Value of Deep-Sea Corals

Several studies document that the diversity, quality and extent of bottom habitats are vital determinants of rockfish diversity, distribution and abundance (Pearcy *et al.* 1989; Carr 1991; O'Connell and Carlisle 1993; Nasby-Lucas *et al.* 2002). Additionally, species richness and community composition over smaller scales also correlate with three-dimensional structure (Love *et al.* 1991; Krieger 1993; Yoklavich *et al.* 2000). Corals create extensive three-dimensional habitat that fishes use for shelter, feeding, spawning and as nursery areas for post-settlement individuals. Studies document diverse faunal associations with deep-sea corals (Heifetz 2002, Krieger and Wing 2002). Gorgonians such as red-tree coral (*Primnoa* spp.), which can grow as large as 7 m and form discrete aggregations, are now widely acknowledged as important fish habitats and are considered essential fish habitat by the North Pacific Fishery Management Council[1] (Witherell and Coon 2001). Likewise organisms that provide three-dimensional structure, such as sponge beds, are also important fish habitats (Freese 2003).

Several studies suggest commercially important fish species are found in association with deep-sea corals, such as Atka mackerel (*Pleurogrammus monopterygius)* and shortspine thornyhead *(Sebastolobus alascanus)* in Alaska (Heifetz 2002). Krieger and Wing (2002) report rockfishes, as well as several other megafaunal assemblages, associated with *Primnoa* corals in the Gulf of Alaska, and highlighted the importance of *Primnoa* to deep-water ecosystems. Rockfishes in Alaska, which have similar life histories to those in the PFMC region, are found in association with the same corals occurring in PFMC waters (Krieger and Wing 2002). Likewise Fosså *et al.* (2002) presents results indicating a dense aggregation of *Sebastes* sp. associated with *Lophelia* corals off the coast of Norway. Husebø *et al.* (2002) found that fish in coral habitat tended to be larger than in non-coral habitat.

Impact of Fishing on Deep-Sea Corals

Deep-sea corals are considered valuable fishing areas. Historically damage to corals from fishing was likely light to moderate as less robust gears and smaller vessels limited damage. This has changed dramatically with larger, more powerful vessels, much stronger synthetic fibers and the advent of roller and rockhopper trawl gears. With increased technology and aids to navigation including fish finders, precision depth profilers, and inexpensive geo-positioning electronics, it is much easier to target specific areas. Longlines and gillnets damage *Lophelia* reefs in Norway (Fosså *et al.* 2002). Hook and line, pot/trap and longline methods occur in and near coral areas and can lead to snagging and breaking of corals as well (Dall 1884, Breeze *et al.* 1997; Fosså *et al.* 2002). Additionally, the setting of traps on corals damages or crushes corals, and traps in set-lines are particularly damaging (Barnette 2001), especially when hauled with hydraulic winches. These modifications allow fishermen to recover gear and catch in

[1] North Pacific FMC region includes all state and U.S. federal waters surrounding Alaska.

areas that previously would have been off-limits to fishing and therefore served as natural refugia.

There is a strong emerging scientific consensus that destructive fishing is having alarming and increasing impacts on seafloors (Watling and Norse 1998; Auster and Langton 1999; Thrush *et al.* 2001; National Research Council (NRC) 2002; Dayton *et al.* 2002; Thrush and Dayton 2002; Pew Oceans Commission 2003). Physical damage occurs to living seafloor structures (e.g., corals, sponges, seagrasses) as well as the geologic structures (e.g., boulders, cobbles, gravel, sand, mud) that serve as nursery areas, refuges, and homes for fishes and organisms living in, on or near the seafloor. The impact of mobile demersal gears, especially bottom trawls, on European deep-sea coral is a major concern (Rogers 1999; Duncan 2001). Hall-Spencer *et al.* (2002) document widespread trawling damage to deep-sea coral reefs at 840-1300 m depth along the West Ireland continental shelf break and at 200 m off West Norway. Trawling also damages deep-sea coral reefs off Norway and Tasmania (Fosså *et al.* 2002; Koslow *et al.* 2000, 2001).

In US waters, few studies evaluate the actual impacts of fishing gear on corals. *Oculina* coral reefs are believed to have been damaged by benthic fishing gears as long ago as the 1970's though this is not well documented (Reed 2002). Shrimp trawlers have been caught illegally fishing in the reserve since its designation in 1984, and the reefs are now nearly totally destroyed (Reed *et al.* this volume). Scleractinians are not the only vulnerable corals; Krieger and Wing (2002) document bycatch of and damage to *Primnoa* from bottom trawls and longline gear in Alaska.

Evaluating the differential impacts of bycatch and habitat damage, and the severity of these impacts among different gear types, is a challenging task. A recent report by Morgan and Chuenpagdee (2003) reviewed over 170 documents on the bycatch and habitat impacts of ten fishing gears and provided a ranking of the ecological impacts of these gears. This report includes an experts' rating of fishing gear impacts to physical and biological habitats and five bycatch groups (i.e., shellfish and crabs, finfish, sharks, marine mammals, and seabirds and sea turtles). These ratings provided the basis for a survey of the ecological severity of the gear impacts sent to another group of experts using the 'damage schedule' approach developed by Chuenpagdee *et al.* (2001a, b). Their responses were combined in one overall ecological severity scale. The fishery experts considered the ecological impacts caused by bottom trawls, bottom gillnets, dredges, and midwater gillnets to be the highest, followed by moderately impacting gears: pots and traps, pelagic and bottom longlines. Finally, gears causing relatively low impacts are midwater trawls, purse seines and hook and line methods.

In this report we compare the distribution of deep-sea coral records along the West Coast of the US and the distribution of groundfish landings in 2000 to determine areas of potential conflict. Next we review deep-sea coral distributions in the context of recent management actions in the Pacific FMC region to alleviate overfishing of groundfish. We then use the Morgan and Chuenpagdee (2003) ranking of fishing gears to develop an ecological footprint (ecological severity of gear multiplied by landings) for each gear involved in the groundfish fleet to highlight the nature of fishing threats to deep-sea corals. Finally we conclude with suggestions of appropriate policy responses.

Methods

Coral Occurrences

Deep-sea coral records along the Pacific coast of the US compiled by Etnoyer and Morgan (2003) are used to examine deep-sea coral distributions (Fig. 2). These records include members of eight cnidarian families recorded in the literature and in institutional databases. Institutions include the NMFS RACEBase, California Academy of Sciences, Scripps Institution of Oceanography, Smithsonian Institution, Monterey Bay Research Institute, Santa Barbara Museum of Natural History, NOAA Office of Exploration and one previous report (Cimberg *et al.* 1981). The eight families (Caryophylliidae, Oculinidae, Antipathidae, Primnoidae, Paragorgiidae, Isididae, Corallidae, Stylasteriidae) were chosen based on their ability to grow large enough to provide habitat for commercially important groundfish. It did not include solitary sclearactinian cup-corals, nor was it exhaustive, thus certain families such as the Paramuricidae are excluded.

Fishing Gear Impacts

A recent study ranking the differential impacts of fishing gears (Morgan and Chuenpagdee 2003; Chuenpagdee *et al.* 2003) is used here to establish the ecological footprint of different fishing gears used in the Pacific coast groundfish fleet (Scholz 2003; Scholz *et al.* 2003).

Using information from NOAA Fisheries for the year 2000, summarized by Scholz *et al.* (2003), we plot the distribution of four fishing gears used in the groundfish fleet (bottom trawls, bottom longlines, pots and traps and hook and line) in 9x9 km blocks. These gears range over the three impacts levels (low, moderate and high) in Morgan and Chuenpagdee (2003). We illustrate the level of catch by these gears throughout the PFMC region. For each gear class we multiplied landings in each 9x9 km cell by 1, 2 or 3 (1 = low, 2= moderate or 3=high impact) to develop a scale of relative ecological impact. Landings by block were arbitrarily split into 5 classes: no landings; 1- 100,000 lbs; 100,001-200,000 lbs; 200,001-300,000 lbs; and over 300,000lbs. Together this information (impact level and landings) gives us an estimate of the ecological footprint of each of these gears for use in policy development to protect deep-sea corals and associated seafloor habitats.

Results

Antipatharian, octocorallian and hydrocorallian records are much more common than scleractinian records in the Northeast Pacific region. The shelf break along the coast of Washington, Oregon and northern California, and the Monterey submarine canyon edge are the areas with the largest number of records. The largest area of localized richness appears to be the Monterey Canyon. This area has been relatively well sampled, and suggests that current records reflect, in part, where researchers have sampled. Records for Stylasteriidae tend to be the nearest to the shore, but there are also records in deeper waters. The California hydrocoral, *Stylaster californicus*, is common to rocky reefs and banks in California, especially banks off southern California, while other Stylasteriidae species are recorded in deeper waters. The Pacific region in general has not been extensively explored for deep-sea corals, and new explorations will undoubtedly document new records and perhaps even new species. DeVogelaere *et al.* (2003) recently recorded *Corallium* sp. from Davidson Seamount, a species entirely absent from the Etnoyer and Morgan (2003) database along the US West Coast.

Plotting the deep-sea coral occurrences with the 2000 landings data in the groundfish fishery (as compiled by Scholz 2003; Scholz *et al.* 2003) shows that there appears to be little overlap with the groundfish fishery (Fig. 3a). Areas of high coral diversity and abundance do not conflict with recent landings in the groundfish fishery. One notable exception is Monterey Canyon, where there is substantial overlap (Fig 3c). In general fishing occurs on the shelf while coral records occur in deeper waters near the shelf break.

Plotting the 2002 groundfish closures (implemented by the PFMC in order to assist in the recovery of overfished rockfish populations) with coral records (Fig. 4) suggests these closures, which are restricted to the shelf, do not overlap many of the known coral occurrence records. This is true along the length of the three Pacific Coast states, with few exceptions.

Finally by plotting fish landings (9x9 km blocks) scaled by the gear ranking (Morgan and Chuenpagdee 2003; Chuenpagdee *et al.* 2003) we develop an ecological footprint for each of the 4 gears in use in the groundfish fleet in 2000 (Scholz 2003; Scholz *et al.* 2003). This plot by fishing gear (Fig. 5) shows the relative difference in gear usage, as well as a severity scale (green, light impact to black, heavy impact) by the different gear types. Bottom trawl gear is the most widely used gear as well as the most ecologically severe, therefore having the largest ecological footprint. The other gears are used extensively throughout the PFMC region, but have smaller footprints.

Discussion

Our qualitative analysis of deep-sea corals shows that five of the eight coral families are widely distributed along the Pacific Coast of North America. The area of highest occurrence is the shelf break, an area of high bathymetric relief. Plots of landings in the groundfish fleet and deep-sea coral occurrences in the region managed by the Pacific Fishery Management Council show interesting patterns that may be difficult to interpret. Groundfish landings in 2000 are mostly confined to the shelf, while deep-sea coral occurrences are greatest along the continental shelf break and Monterey submarine canyon. While it is conceivable that these records reflect greater sampling intensity, especially in the Monterey Bay region, it is not likely that the shelf break has been better sampled than the shelf region. This pattern suggests that either there is limited overlap between fishery operations and deep-sea corals, or that fishing has already had a substantial negative impact on coral occurrences. Since our records do not reflect historic coral distribution, it is difficult to know the impacts of past fishing.

As early as 1873, Dall reports that *Stylaster* corals from the Farallones Islands in northern California were entangled in fishermen's hooks and brought to the surface. Pauly (1995) refers to the erosion of our knowledge of abundance, range and distribution of species resulting from human impacts as a shifting baseline. That is, we view incremental loss as insignificant because we have no memory of the full magnitude of our impact over time frames larger than our individual history. It is possible that over 100 years of fishing and at least 30 years of trawling have impacted corals to the degree that we are no longer have an accurate picture of their distribution and abundance. Anecdotal information from fishermen in the Canadian Maritimes suggests that long-time fishermen have been well aware of these corals and have witnessed a notable decline (records from the 1800s, see Gass 2002). Given the potential ages of gorgonians – hundreds to thousands of years (Druffel *et al.* 1995; Risk *et al.* 2002; Andrews *et al.* 2002; Roark *et al.* 2003) – these species might be irrevocably harmed by a single trawl pass and not recover.

Fishing closures implemented in 2002 to help depleted rockfishes may have the unintended consequence of redirecting fishing effort into areas with deep-sea corals as fishermen move further offshore in search of groundfish. Further examination of this question is needed based on current data, but conventional management that is focused on maximizing catch of a few species is all too likely to make such unintended errors. Without a holistic approach such as ecosystem-based management, fishery managers will continue to witness consequences to non-target species which they are unable to predict and which results in the overall degradation of the system (see Springer *et al.* 2003).

Bottom trawling has the largest ecological footprint in this study (landings x severity of impact, Fig. 5) and is likely to move deeper in pursuit of fish (Roberts 2002). Bottom longlines cause moderate impacts but have a rather small overall ecological footprint because of their much more limited use in the PFMC region. Pots/traps and hook and line methods are similarly limited in impact and use in this region. Bottom longlines can damage corals (Krieger and Wing 2002; Gass 2002); longlines, like trawl nets, frequently remove coral trees from the rocks and boulders they grow upon (Kreiger and Wing 2002). But bottom trawling is the most ecologically damaging method of fishing (Morgan and Chuenpagdee 2003). The benthic impacts of this mobile fishing gear has been compared to clear-cutting techniques in old growth forests (Watling and Norse 1998).

The groundfish closures on the shelf left the continental slope open to fishing, increasing the chances that fishermen might harm corals. The shelf break is important habitat for deep-sea corals (Leverette and Metaxas, this volume), and fishing along the shelf break will likely have a large impact on corals. Research on rockfishes and their habitat relationships is ongoing in this region (Yoklavich *et al.* 2000; Nasby-Lucas *et al.* 2002), but there has been little research conducted on the associations of rockfishes and corals. The Northeast Pacific has far more species of rockfishes than elsewhere (96 species vs. 4 species in the North Atlantic), making it likely that at least some of these species are habitat specialists. Knowledge of habitat relationships of rockfish is increasing, but we may never understand the degree to which habitat degradation has occurred, or its impact on depleted populations. More research on these types of relationships for the various rockfish species is needed. Likewise better documentation by submersibles and remote operated vehicles (ROVs) is needed in areas of high rockfish catch.

Management Implications

Ecosystem-based management (EBM) is our best hope for maintaining all interacting components of an ecosystem (Dayton *et al.* 1995; Pitcher and Pauly 1998). Conventional management goals targeting maximum sustainable yield are ill-equipped to account for deep-sea corals, as well as other seafloor habitats, in the absence of a directed fishery. Provisions for EFH and marine protected areas (MPAs) are important steps in the process of moving towards EBM, but are not sufficient. Ecosystem-based management will progress only by acknowledging differential impacts of fishing gears and by restricting certain gears to protect not just target species but their habitats and associated species as well (i.e., deep-sea corals, other invertebrates and non-target fish species).

There is urgent need for appropriate policy responses to minimize fishing gear impacts on seafloor habitats. The severity ranking of the ten commonly used gears in the US provides a basis for formulating fisheries policies aimed at protecting corals (Morgan and Chuenpagdee 2003; Chuenpagdee *et al.* 2003). Fishery policies should encourage a shift from gears with higher impacts to gears with lower impacts for Pacific groundfish among the four gear types used by the groundfish fleet (Scholz 2003; Scholz *et al.* 2003, see Fig. 5). A good example of this "shifting gears" is the California spot prawn (*Pandalus platyceros*) fishery, where rockfish bycatch is being greatly reduced by shifting from bottom trawls to traps (Reilly and Geibel 2002). Reduced use of bottom trawls not only benefits overfished rockfish stocks, but also lessens damage to benthic habitat on which spot prawns, rockfishes and deep-sea coral species rely. Prawns caught in traps also have a higher market value because they are less damaged by fishing gear. Clearly, shifting gears pays off in the long run, as fishers can maintain high economic returns, without long-term damage to groundfish habitats. However, this gear shift is initially an expensive proposition for fishermen, and incentives are one way to encourage fishers to voluntarily shift gears that is worth exploring.

Throughout the US, fishery management councils are required to address the impacts of fishing through the National Environmental Protection Act (NEPA) by developing Environmental Impact Reports (EIR) to address the multiple impacts of fishing. Furthermore the US Magnuson-Stevens Fishery Conservation and Management Act, as reauthorized and amended in 1996 by the Sustainable Fisheries Act, mandates more attention to habitat protection, including designation of essential fish habitat and consideration of actions to conserve such habitat (Section 110). A number of actions have been taken in the US to address habitat impacts of fishing. For example, measures to reduce habitat damage include banning bottom trawls throughout the 1.5 million square miles of the Western Pacific Fishery Management Council region (Code of Federal Regulations 2002) and closed areas for the groundfish fishery on Georges Bank in New England (Collie *et al.* 1997). Moreover, areas closed to trawls to reduce bycatch, such as closures aimed at reducing bycatch of red king crabs (*Paralithodes camtschaticus*) in federal waters off Alaska, might also have substantial benefits for other benthic species.

Proactive closures, such as MPAs aimed at the most destructive gears in the most sensitive habitats, offer a robust means to protect both habitat and fishermen without the need for draconian measures such as the massive closures from Canada to Mexico as implemented in 2002 by the PFMC. Effective implementation of MPAs depends largely on the acceptance of user groups and others affected by it. Thus a fair, transparent and inclusive process in the design can facilitate implementation and can be achieved by incorporating the differences in the ways fishing gears impact marine ecosystems. The most destructive gears should be managed using appropriately stringent policies. Complete prohibition of use in ecologically sensitive areas, such as concentrations of deep-sea corals, is an example. One useful management measure is banning the use of roller and rockhopper gear on bottom trawls that allow fishing in these coral habitats. This is the approach taken in the Ocean Habitat Protection Act (HR 1690) legislation introduced in the 108^{th} US Congress.

At the same time fishery management councils can provide incentives through additional catch allocations to fishermen using less destructive gears and technologies. In the PMFC region's groundfish fishery, a matrix of habitat sensitivity and gear impact is one way forward in addressing catch allocation among the four groundfish gear types. The severity ranking of fishing gears suggests the need for policies that encourage shifting from high-impact gears to low-impact gears. Regardless of the gear, where impacts occur to threatened or endangered species or sensitive habitats, their management should be considered high priority. In cases where habitat impacts cannot be addressed by alternative fishing gears and practices, implementing closed areas will protect healthy ocean ecosystems and species (NRC 2002; Collie *et al.* 1997).

Of course, scientific research is essential to intelligent fishery management. We recommend more mapping research on deep-sea coral distribution and abundance and determining the degree to which coral aggregations provide essential fish habitat for groundfish in the PFMC region and beyond. Managers must also move to a more holistic appreciation of the impacts of fishing, looking not only at impacts to target species such as rockfish, but the collateral impacts to the ecosystems that support them.

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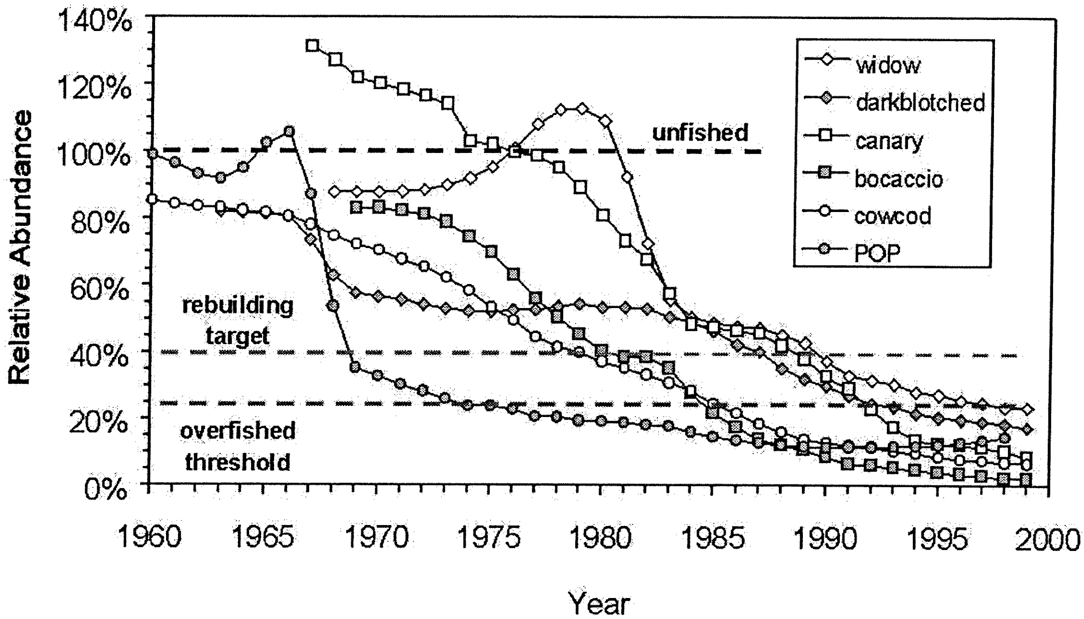

Fig. 1 Decline of six species of west coast rockfish and management thresholds (from S. Ralston, personal communication, NOAA Fisheries, based on Stock Assessments of NOAA Fisheries).

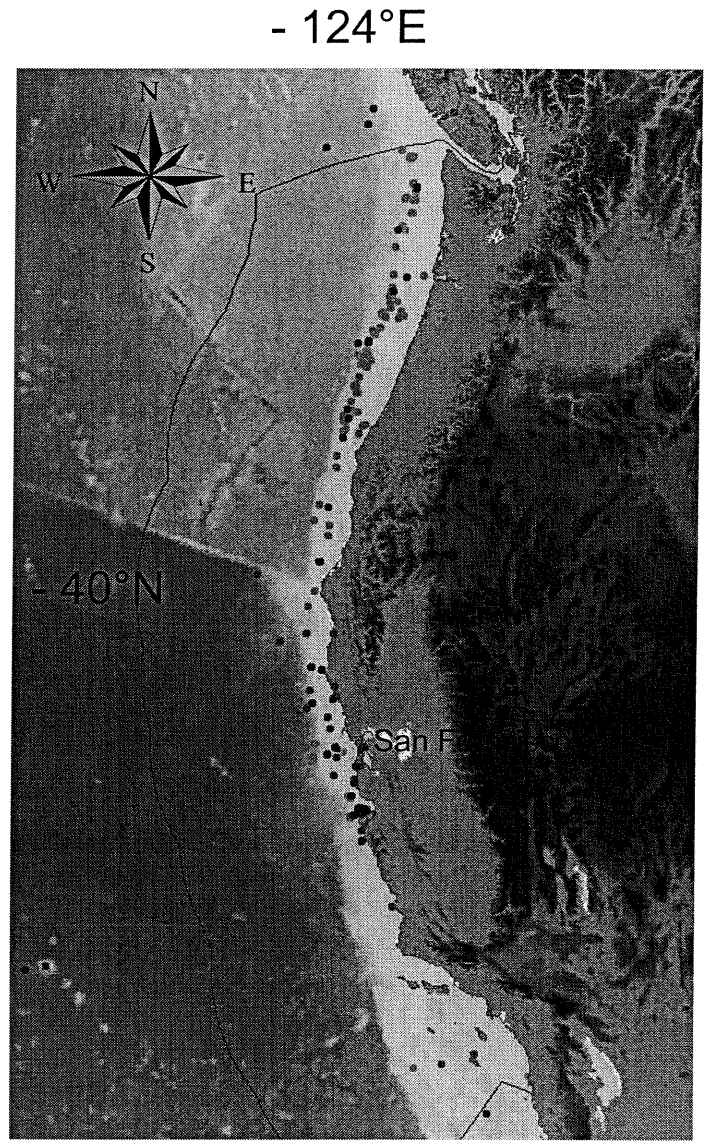

Fig. 2 Deep-sea coral records from Etnoyer and Morgan (2003). Teal – Stylasteriidae, Pink – Isididae, Purple – Paragorgiidae, Blue – Primnoidae, Green – Antipathidae. Other families are rare in the database for the US West Coast.

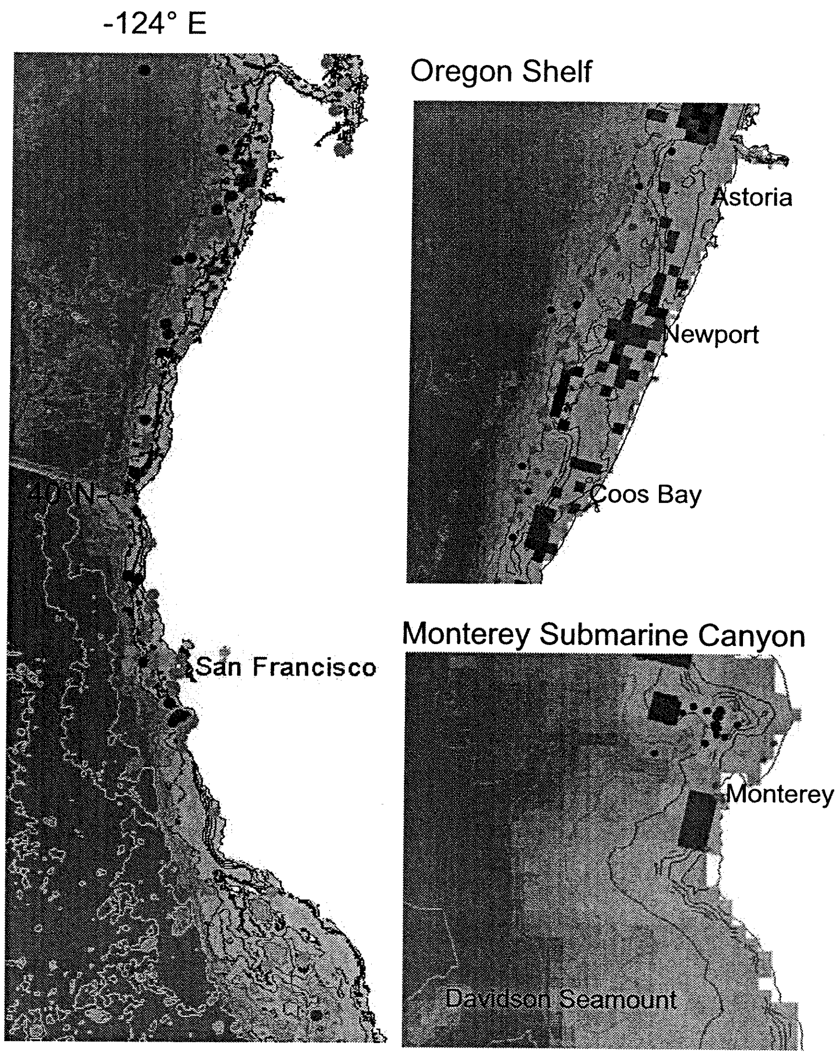

Fig. 3 A) Occurrences of cold water corals and groundfish fleet catch along the Pacific west coast (Darker red indicates larger landings. Color code of coral records; light green - Antipathidae, teal - Stylasteriidae, pink – Isididae, purple – Paragorgiidae, dark blue – Primnoidae.) B) Oregon shelf showing abundant records along the shelf break. C) Monterey Canyon showing abundant and diverse records at the canyon break.

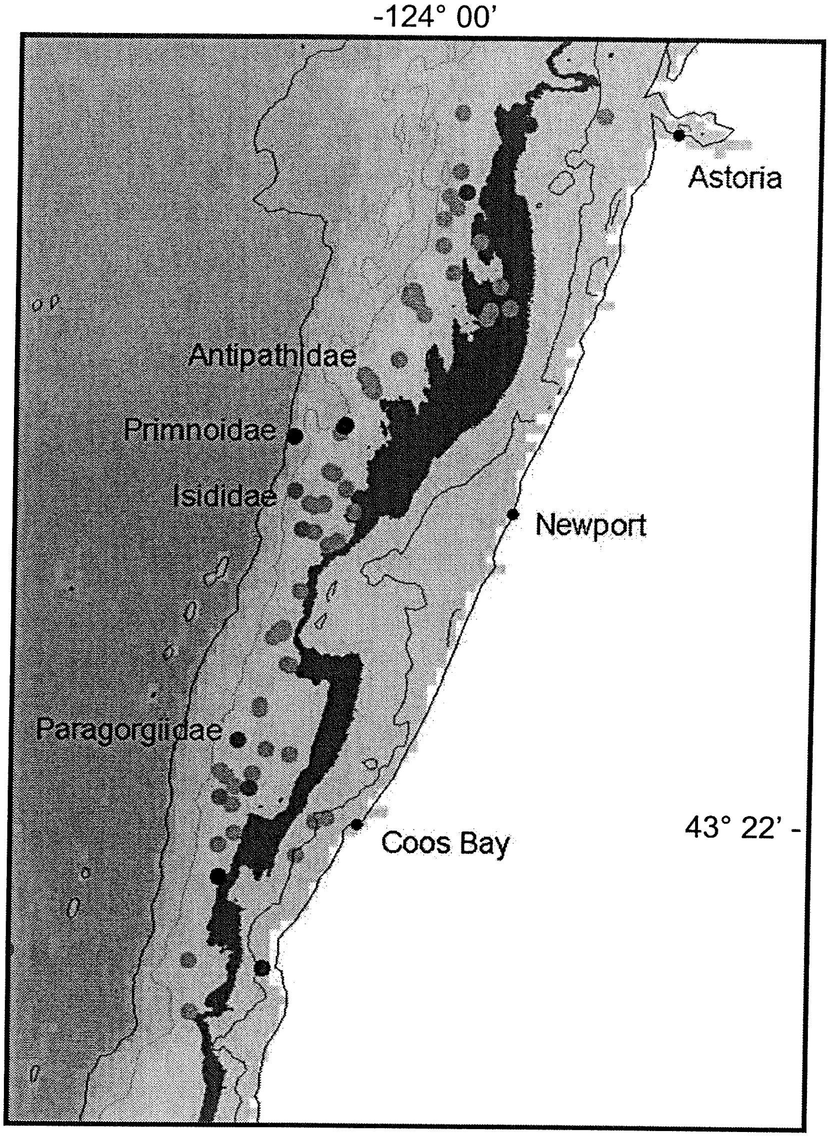

Fig. 4 Groundfish closures (red) as implemented by PFMC to protect rockfish populations and deep-sea coral occurrences offshore of Oregon (Etnoyer and Morgan 2003).

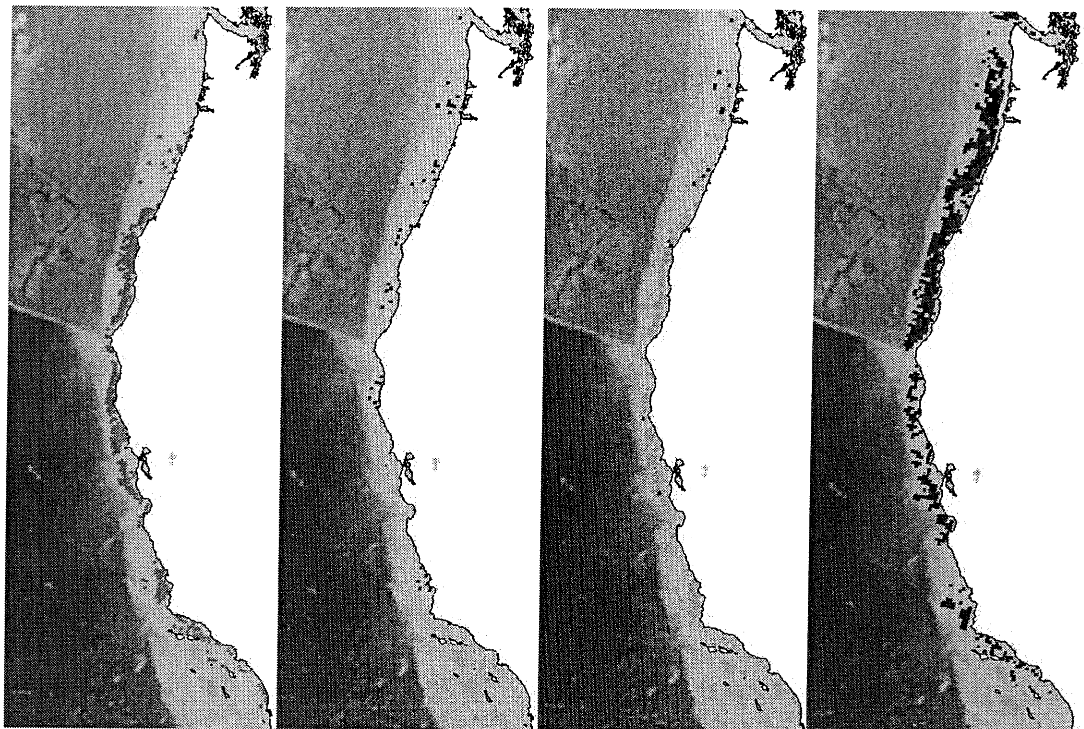

Fig. 5 Ecological footprint (landings x gear ranking) for four gear types used in the Pacific Fishery Management Council region to land groundfish. Impact scale: green – light, yellow –moderate, red – heavy, black – very heavy. Landings from year 2000 see Scholz et al. (2003). Gear ranking from Morgan and Chuenpagdee (2003).